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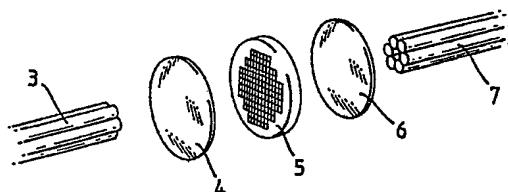
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## (54) Optical switching arrangement

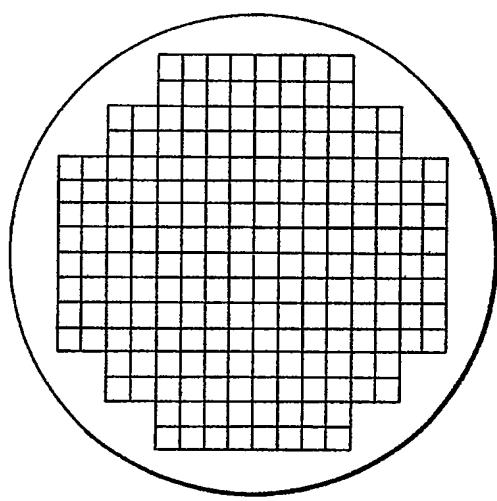
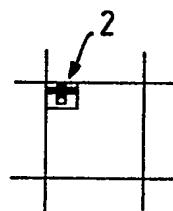
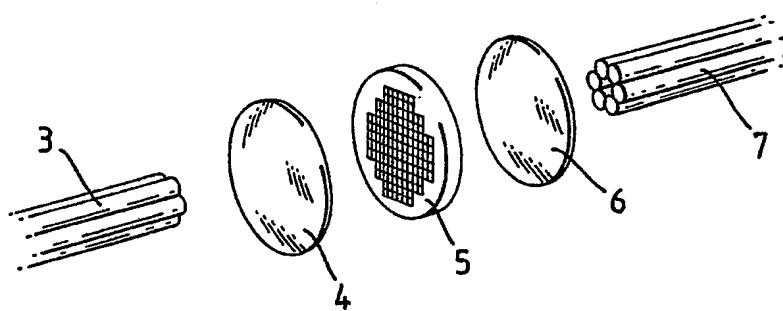
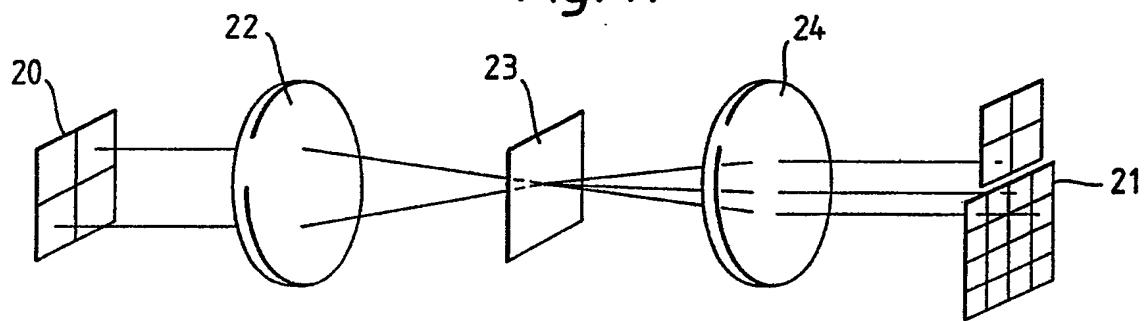
(57) An optical switching arrangement includes a first optical fibre bundle 3 from which a multiple light beam is directed via a lens system 4 on to an array 5 of multiple quantum well (MQW) devices. After passing through the array the beam is focussed by another lens system 6 on to an output fibre bundle 7. The array allows switching between the beam's input configuration and a desired output configuration. The MQW devices are operable in a detection mode, whereby a desired re-configuration pattern is input optically over one of the fibres and the detected interference pattern that results (which can form a hologram) is conveyed over electrical connections from each device to an electronic store. When switching is required the pattern is recalled and applied as modulation to the devices. The devices may use the self-electro-optic effect or a variant comprising stacked, alternate p-type and n-type layers.

Fig. 3.



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The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

*Fig. 1.**Fig. 2.**Fig. 3.**Fig. 4.*

## SPECIFICATION

## Optical switching arrangement

- 5 This invention relates to optical switching arrangements using devices each of which can function both as a detector and as a modulator. Examples of such devices include multiple quantum well (MQW) devices.
- 10 One example of such an MQW device is described in a paper "Novel hybrid optically bistable switch : the quantum well self-electro-optic device" by D.A.B. Miller et al, at pp 13-16 of Applied Physics Letters, 45(1), 1 July, 1984. This device, referred to as the
- 15 SEED uses a sandwich structure of alternate layers of GaAs and GaAlAs in a p-i-n diode structure. That is, the sandwich structure is in effect the "active" portion of the device. If a light beam falls on this device and passes through it, it can be modulated in accordance with electrical potentials applied across the SEED. Hence we get an output beam which is a modulated version of an input beam.

Another device which has somewhat similar properties is described in our Patent Application No. 25 8517534 (P.A. Kirkby 8). This specification describes an optical fibre network component for connection between an electro-optical source and a detector, which component includes an optical fibre coupling in which the end of one optical fibre is optically coupled with the end of another, wherein interposed between the coupled ends of the two fibres is a transmissive detector and modulator (TDAM).

Such a TDAM is constituted by a multilayer semiconductive device having a stack of electrically 35 commoned sub-micron thickness p-type layer interleaved with a stack of electrically commoned sub-micron thickness n-type layers.

Thus the two devices specifically mentioned above have similarities, but the SEED uses layers which, 40 according to Miller et al, are not intentionally doped, whereas the TDAM uses alternate p-type and n-type layers. Thus the SEED is a compositional superlattice (CS) device, while the TDAM is a doping superlattice (DS) device. The CS device was the first of these to be 45 investigated. However, the TDAM has certain fabrication advantages, and also some operational advantages, e.g. a wider wavelength range.

An object of the present invention is to extend the usefulness of components each of which can 50 function both as a detector and as a modulator. As mentioned, examples of such devices include the SEED and the TDAM, which will be collectively referred to herein as MQW devices.

According to the present invention there is 55 provided an optical switching arrangement which includes a first optical fibre bundle from which a multiple light beam is directed via a first lens system on to one side of a multiple assembly of devices each of which can function both as a detector and as a 60 modulator, wherein a second lens system directs the light leaving that assembly on to a second optical fibre bundle, wherein electrical connections extend between the individual devices of the assembly and associated circuitry via which selected beams of light 65 from the first fibre bundle can be modulated and

re-routed to appropriate ones of the fibres of the second bundle, said modulation and re-routing being effected under the control of electrical signals applied via said electrical interconnections.

- 70 According to the present invention there is also provided an optical switching arrangement which includes a first optical fibre bundle from which a multiple light beam is directed via a first lens system on to one side of a multiple assembly of MQW 75 devices, wherein a second lens system on the other side of the multiple assembly directs the light leaving that assembly on to a second optical fibre bundle, wherein electrical connections extend between the individual devices of the assembly and associated 80 circuitry via which selected beams of light from the first fibre bundle can be modulated and re-routed to appropriate ones of the fibres of the second bundle, said modulation and re-routing being effected under the control of electrical signals applied via said 85 electrical interconnections.

The MQW devices as already indicated can function both in the detection and in the modulation mode, so that the pattern of re-routing, or reconfiguration of the input beams which is needed, 90 can be signalled to the assembly of MQW devices by interference between two light beams. This pattern is then recorded in storage means included in the associated electronic circuitry for future use. A number of such patterns can be thus recorded, in 95 which case means is provided to select whichever is needed for use.

Embodiments of the invention will now be described with reference to the accompanying drawing, in which Figure 1 is a plan view of an 100 assembly of MQW devices, in the present instance TDAM's, as used in a system embodying the invention, Figure 2 is an enlarged view of one of the elements of Figure 1, Figure 3 is a perspective view of the "optics" of a system embodying the invention, 105 and Figure 4 is a similar view of another embodiment of the invention.

The assembly, see Figure 1, is in the present case circular, and each element is square. Figure 2 shows one of the elements enlarged, from which it will be seen that the optically active area 1 is considerably larger than the associated electronic function 2. Such an array may include a large number of elements, e.g. 1000 × 1000 in a matrix. The electrical connections to these functions are not shown; they 115 can be made in a similar way to that used for the connections to individual elements of matrix-addressed active silicon backed liquid crystal devices.

Figure 3 shows the optical arrangements of the 120 system. Here we see an input fibre bundle 3 whose end, i.e. the ends of the individual fibres of that bundle, is "aimed" at a lens system represented by the lens 4. Next in line is the multiple device assembly 5; note that the associated electronics and 125 the connections between that and the assembly 5 are not shown. The focussing can be such that each individual beam from the fibre of the bundle is directed on to different sets of MQW elements.

On the other side of the assembly 5, we see 130 another lens assembly, represented by the lens 6,

which focusses the beams emergent from the assembly 5 on to the ends of the fibres of another bundle 7. The focussing effected by the lens system 6 can be altered to focus the beams from different sets 5 of elements on to the ends of the fibres 7.

The two lens systems 4 and 6 could in some cases each be single lenses, or in other cases multi-lens systems.

Thus the pattern of the beams from the fibre 10 bundle 3 can be reconfigured before the beams reach the output bundle 7. This reconfiguration is effected under the control of the electrical connections to the devices of the assembly 5, by altering the modulation pattern within each set of 15 MQW elements so that any desired reconfiguration is possible.

As will be seen from, for instance, our above-mentioned patent application, the MQW 20 devices can also function in a detection mode. This is exploited in the present arrangement; thus the desired reconfiguration pattern can be signalled in optically via one of the fibre bundles, and such signals detected by the MQW devices functioning in their detection mode. The results of these detections 25 are sent via the above-mentioned electrical connections to storage means so that they are stored in the associated electronics. The interference patterns thus signalled in are then, in effect, stored as mathematical functions.

30 The fibre bundles referred to can be a bundle whose fibres and the light they convey are related to each other, or they can be individual (e.g. monomode) fibres.

Thus the arrangement provides the ability to 35 generate the hologram for a desired interconnection pattern by optical means and to store the information therefor electrically. Thus there is a considerable saving in time and energy compared with a mathematical derivation of the pattern.

40 One reconfiguration that can be effected in the above manner is an incremental rotation of the pattern defined by the fibres of the bundle. This rotation can be continuous or discontinuous, and may be applied to the topological manipulation of 45 two-dimensional wavefronts which are not derived from optical fibres e.g. expanded plane wavefronts. This involves co-ordinate transformation on freely propagating image wavefronts, which is important in such applications as pattern classification and 50 image processing.

We now consider extensions and applications of the techniques referred to above. There is a requirement in both telecommunications and computing for devices which can reconfigure, in the 55 general case, N input channels into M output channels. Practical applications include network routing and alignment of data in an array processor. The traditional solution is the NXM crossbar switch. The time required by this switch is  $O(\log N)$  or  $O(\log 60 M)$  gate delays, and the number of gates required is N.M. The term  $O(\log N)$  means the order of  $\log N$  rather than the order of N.0.

The number of gates is reduced in the Batcher sorting network to  $O(N(\log N)^2)$ , but  $O(\log N)^2$  time 65 units are required. Alternatively, the Omega network

can be used. This consists of  $\log N$  stages, where each stage is a perfect shuffle followed by  $N/2$  switching elements. Therefore, the total number of switching elements is  $N/2 \log N$ , and the time delay is

70  $\log N$ . The greater efficiency of the Omega network is gained by processing the channels in parallel. Unfortunately, it is only unidimensional parallelism and is not entirely conflict free. It may be profitable to consider the two-dimensional parallelism, i.e. 75 left-right-up-down switching, which is possible with (laterally) extended light beams and optical switching arrays.

In one such array, Figure 4, a relationship exists between a point in the input plane 20 and a point, or 80 group of points, in the output plane 21 such that a translation of the input point results in a corresponding translation of the output point(s). The input plane 20 represents the end of an optical fibre bundle, i.e. the end from which incoming light reaches the lens system 22, while the plane 21 85 represents the end of the output optical fibre bundle. Here also we have a first lens (or lens system) 22, a hologram 23 and a second lens (or lens system) 24. As an interconnection strategy this is most profitably 90 exploited as a one-to-many switch in conjunction with ancillary beams to enable or disable the desired or unwanted points. The number of resolution elements required for the hologram is equal to the number of output channels (multiplexed by coding 95 and beam-shaping factors) for the *whole* of the hologram.

The hologram for the arrangement of Figure 4 can be written on an electrically addressed spatial light modulator (SLM). The mathematical form of the 100 hologram is generated by computer calculation. Alternatively, an optically addressed SLM with some form of erasable memory could be used. The hologram is written by interfering a beam issuing from the required channels in the output array, with 105 a beam which is conjugate to the input beam. Thus, a second input array 30 is placed in the image plane of the original input array 21, Figure 6. When a new interconnect is required, the hologram is erased and a new one is formed. The wavelength of the light

110 used to form the hologram must differ from that of the light to be switched, in order that the hologram is not erased in use. This leads to aberrations in the performance of the hologram, and is not entirely satisfactory for this reason. Hence a device which 115 exhibits degenerate four wave mixing is preferred, and the beams from the two input arrays (now of the same wavelength) are maintained during the switching operation of the system. Unfortunately, a problem remains with this system, also. The 120 degenerate four wave mixer is usually of such a thickness (to maintain diffraction efficiency with weak optical non-linearity), that the spatial extent of the output array which can be addressed is limited. Materials with larger non-linearities, such as liquid 125 crystals close to the nematic/isotropic transition, are of considerable advantage in this respect.

A relatively simple (in terms of system enactment rather than device design) alternative exists for the two-dimensional TDAM arrays. The TDAM as 130 already indicated, is a device (e.g. multiple quantum

wells on GaAs) which can record an interference pattern, and subsequently reinstate that pattern as an amplitude modulation. In this case, all the required interference patterns could be learnt by the device and stored in an electronic memory. When switching is required, the pattern is recalled from memory. An added attraction of this device is the possibility of analogue modulation which reduces the resolution requirements on the array.

Reverting to the system of Figure 4, as indicated this shows a method of forming the interconnect hologram in a system in which the input and output are fixed. A "dummy" array 30 is placed in a conjugate position to the input bundle 20. In this context, "conjugate position" means the image position if there is nothing in the plane 23. To write the required interconnect, the expected input pattern is composed on 30 and the required output pattern on 21. These interfere at the hologram plane 23 and the hologram is written. This requires that light can be transmitted in both directions in the output bundle.

To utilise the hologram, the bundle 30 is switched off and the input applied to 20. The bundle 21 then receives the connect output pattern.

#### CLAIMS

1. An optical switching arrangement which includes a first optical fibre bundle from which a multiple light beam is directed via a first lens system on to one side of a multiple assembly of devices each of which can function both as a detector and as a modulator, wherein a second lens system directs the light leaving that assembly on to a second optical fibre bundle, wherein electrical connections extend between the individual devices of the assembly and associated circuitry via which selected beams of light from the first fibre bundle can be modulated and re-routed to appropriate ones of the fibres of the second bundle, said modulation and re-routing being effected under the control of electrical signals applied via said electrical interconnections.
2. An optical switching arrangement which includes a first optical fibre bundle from which a multiple light beam is directed via a first lens system on to one side of a multiple assembly of MQW devices, wherein a second lens system on the other side of the multiple assembly directs the light leaving that assembly on to a second optical fibre bundle, wherein electrical connections extend between the individual devices of the assembly and associated circuitry via which selected beams of light from the first fibre bundle can be modulated and re-routed to appropriate ones of the fibres of the second bundle, said modulation and re-routing being effected under the control of electrical signals applied via said electrical interconnections.
3. An arrangement as claimed in claim 1 or 2, and in which a hologram is formed on said multiple assembly when the arrangement is in use.
4. An arrangement as claimed in claim 3, in which the hologram is supplied to the arrangement via one of the optical fibre bundles so as to be detected by the devices of the assembly, and in

which signals representative of the hologram are applied from the assembly to electrical storage means.

5. An arrangement as claimed in claim 2, in which an additional optical fibre bundle is located adjacent to the output optical fibre bundle, from which a hologram can be transmitted into the assembly of devices.
6. An optical switching arrangement, substantially as described with reference to Figures 1, 2 and 3, or to Figures 1, 2 and 4 of the accompanying drawings.

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